Reduction of Ground Water Flow by Promoting Clogging Effect of Soil Particles

T. Tamai
TEPCO Power Grid, Tokyo, Japan
tamai.takeshi@tepco.co.jp

T. Shiono, N. Sorimachi, T. Tsukada & F. Kawashima
Tokyo Electric Power Company Holdings, Tokyo, Japan

ABSTRACT:
Grouting was conducted to reduce groundwater flow in the bedrock of a reservoir of a pumped storage power plant, located in the site where the ground water level is low. We conducted grouting around the bottom of the reservoir, due to difficulty of forming the grout curtain reaching the low permeable layer of the bedrock. To reduce the permeability of bed rock with the smaller volume of grout, we invented a method to promote clogging effect artificially by spreading soil particles into reservoir water. The soil particles were obtained from the residual horticultural soil after being screened, collected near the reservoir, in order to reduce the cost. This paper summarizes the results and evaluation of laboratory tests, field tests and application of the invented method.

Keywords: soil particles, clogging, groundwater flow, reservoir, grouting

1. OUTLINE OF CLOGGING PROMOTION METHOD

Grouting was conducted at Yashio dam reservoir, the upper reservoir of the Shiobara pumped storage power plant of Tokyo Electric Power Company with a maximum output of 900 MW, in order to reduce relatively large amount of water leakage seeping into the bedrock of the reservoir. Curtain grouting was abandoned because of the high permeability rock existed so deep under the bed rock that it was difficult to extend the curtain grouting to low permeable rock layer. Therefore, instead of curtain grouting, we planned to apply grouting at the bottom of the reservoir, encircling from both banks, as shown in Fig. 1(a) and 1(b) (Kawashima, F., et al. 2010).

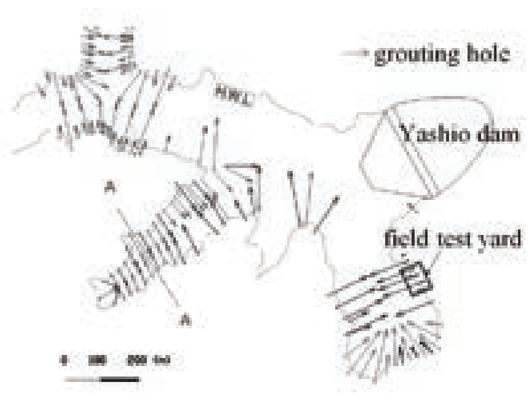


Figure 1(a). Design of the grouting (Plan)

However, since the grouting area was large, we considered relatively wide spacing between each grouting hole, for rough grouting. In addition, we made a study on an auxiliary method to promote clogging artificially by spreading fine soil particles in the reservoir (hereinafter referred to as the clogging promotion method).
Since large amount of soil particles were expected to be used by the clogging promotion method, materials were to be obtained at lowest cost possible. Surveys were made to seek for applicable materials around the site, since few soil particles were available near the site. (Asphalt facing was adopted at Yashio Dam because few core materials were available in the vicinity.) Surveys revealed that screened soil particles were discarded at a horticultural soil plant (known as Kanumatsuchi), located 40 km from the dam site. Kanumatsuchi is sandy, volcanic cohesive soil.

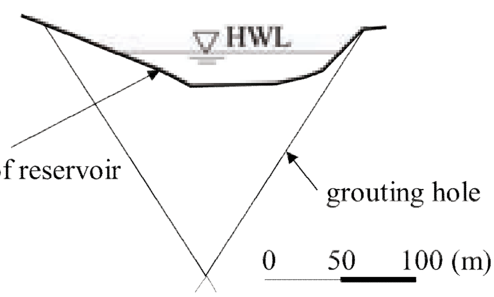


Figure 1(b). Design of the grouting (A-A cross section)

The density of screened soil particle is 2.5 g/cm^3, including twenty percent of particles smaller than five micro meters, and did not contain toxic substances. These characteristics are suitable for the material of promoting clogging method. In addition, stable supply of 20 to 30 m^3/day was ensured.

2. FIELD TEST OF CLOGGING PROMOTION METHOD

2.1. Field test of clogging promotion method

Soil particles were mixed with water and turned into slurry, transported by a barge, and spread into the reservoir. As for the concentration of soil particle slurry, a flow time of ten seconds or less had to be achieved in order to pump through pipes, referring to the performance of cement milk used for grouting. In addition, the ratio of soil particles to water (S:W) was applied at 1:2, so as to minimize the capacity of the barge for transporting soil particle slurry. The applied ratio of S:W = 1:2 proved to achieve the flow time of ten seconds or less, after mixing the slurry for approximately ten minutes.
The field verification tests were conducted for clogging promotion method. The method settles out the soil particles naturally. The verification tests were conducted in the area encircled by net, to prevent soil particles from diffusing throughout the reservoir, as shown Fig.2.
To keep turbidity of the reservoir by soil particles as long as possible, for effective clogging, input rate of slurry was examined. Input rate of slurry was measured at the point when slurry is distributed uniformly inside the net (hereinafter referred to as standard turbidity). Turbidity was measured at a water depth of approximately six meters. Fig. 2 shows the method of spreading soil particles in the reservoir.

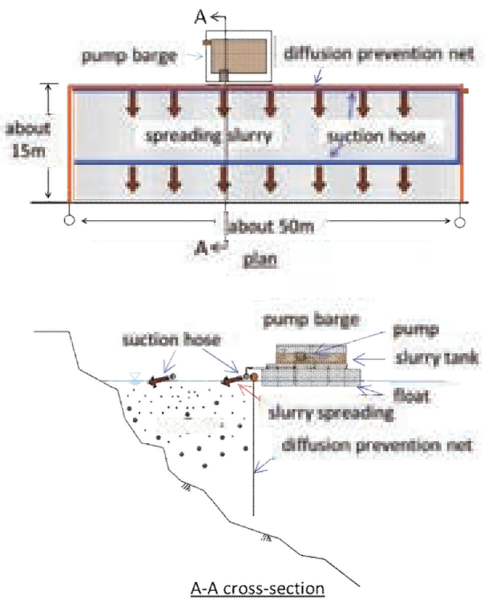
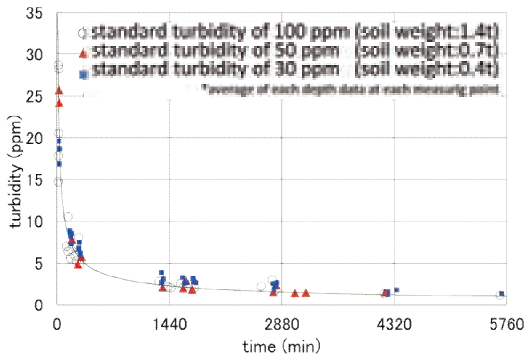


Figure 2. Outline of spreading soil particles

2.2. Study of standard turbidity

Fig. 3 shows the time history of turbidity, varying with standard turbidity, and integrated turbidity (turbidity multiplied by time).



standard turbidity (ppm)	integrated turbidity (ppm·day)			
	0-24hr	24-48hr	48-72hr	72-96hr
100	6	2	2	1
50	5.2	2	2	1
30	5.2	2	2	1

Figure 3. Result of field tests (time history of turbidity of each initial turbidity case)

Immediately after the input, turbidity varied according to standard turbidity, however, turbidities in all cases became nearly equal after approximately two hours. In addition, turbidity decreasing curves were all similar in shape, and integrated turbidity had little or no difference. Based on the results, standard turbidity of 30 ppm was adopted. On the other hand, laboratory tests were conducted to verify the reason why standard turbidity had no influence on turbidity decreasing curves, using the equipment shown in Fig. 4.

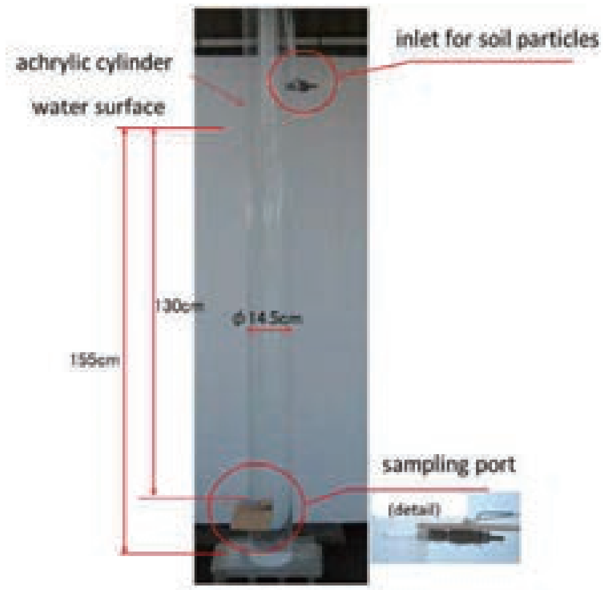


Figure 4. Outline of the equipment of laboratory test (particle settling test)

Tests were conducted at standard turbidities of 1000, 500, 100 and 30 ppm. Visual inspection of soil particles' settlement confirmed that settlement of relatively large soil particles creates a wake flow, which draws in small particles subsequently. It was therefore assumed that wake flow have outstanding effect, and that maintaining turbidity is difficult where large particles are included. Based on the above results and economic efficiency, standard turbidity of 30 ppm was adopted.

3. VERIFICATION OF CLOGGING IN CRACKS

Tests using parallel plates, for simulating cracks, were conducted to verify two aspects of the clogging using soil particles. One is the influence of the width of the crack, and the other is the influence of back pressure. The influence of back pressure was examined since the reservoir of a pumped storage power plant have rapid drawdown, causing back pressure, which may wash out the clogged particles. Fig. 5(a) and 5(b) shows the description of test equipment.

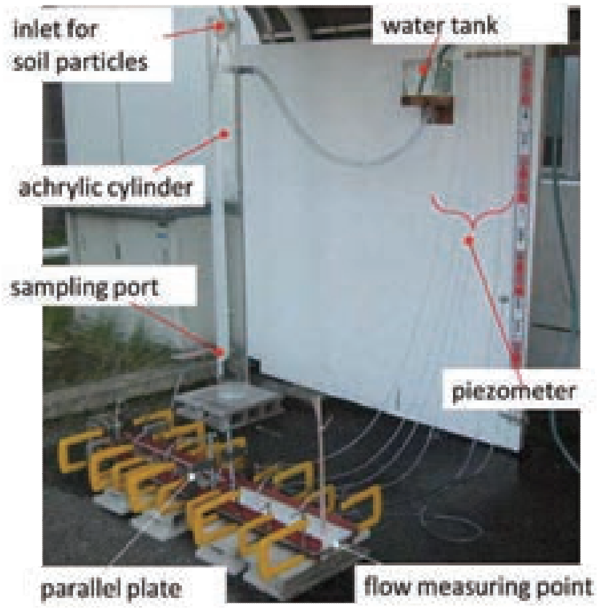


Figure 5(a). Equipment of laboratory tests

Table 1. Condition of laboratory tests in each case

		The velocity ratio of each case against the velocity of the case 2		
		0.75	1	1.5
area/slit	$1mm^2$ (a=1 × b=1mm)	CASE 1 number of slit : 12 sectional area of slit : $12mm^2$ initial flow: 600ml/min.	CASE 2 number of slit : 9 sectional area of slit : $9mm^2$ initial flow: 600ml/min.	CASE 3 number of slit : 6 sectional area of slit : $6mm^2$ initial flow: 600ml/min.
	$2mm^2$ (a=1 × b=2mm)		CASE 4 number of slit : 5 sectional area of slit : $10mm^2$ initial flow: 670ml/min.	CASE 5 number of slit : 3 sectional area of slit : $6mm^2$ initial flow: 600ml/min.
	$4mm^2$ (a=2 × b=2mm)			CASE 6 number of slit : 3 sectional area of slit : $12mm^2$ initial flow:1200ml/min.

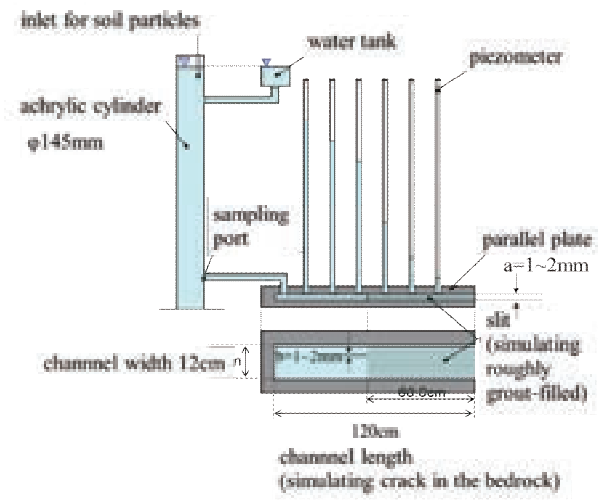


Figure 5(b). Outline of the equipment of laboratory tests

3.1. Verification of short-term clogging

Table 1 shows the test cases to verify the parameters affecting clogging (crack width and flow velocity). As shown in Fig. 5(b), slit zone was installed at the downstream side of the parallel plates, to simulate cracks being roughly filled with grouting. The flow velocity at the parallel plates in case 6 is equivalent to the suction strength of four to five (suction flow velocity of approximately 6 to 10 cm/sec), while in other cases three (suction flow velocity of approximately 4 cm/sec). The suction strength was measured in field submersible surveys, where suction strength indicates the degree of suction flow velocity. Suction strength was measured by watching the movement of colored water sucked into the inlet hole. The relationship between movement of colored water and suction velocity were confirmed by field tests. The input of the soil was set to 10.3 g each time, to be equivalent to the input per unit area of previous field test, in case of natural settlement method. In Table 1, flow velocities are shown as the ratio to the velocity of case 2 (111.1 cm/sec).

Fig. 6 shows the result of case 1. In case 1, by inputting slurry four times, flow decreased from 600 ml/min to 240 ml/min, approximately 60% of the initial flow, after 2.5 hours. Water head shows that clogging occurred at the transition point from parallel plates to slit zone. From the observation, the clogging was first induced by relatively large particles, followed by fine particles gradually filling the remained space.

Fig. 7 shows the particle size distributions of the clogged soils for each cases. Comparing to original slurry (i.e., input slurry), clogged particle grading is decreased in smaller than 20 micro meter and increased from 20 to 60 micro meter. Table 2 shows the results of short-term tests. The results indicates the tendency that clogging is induced by relatively small slit and low velocity. On the other hand, clogging will not be induced with large opening of parallel plates and high velocity, as shown in case 6.

It was verified that clogging developed by large particles first, followed by particles of 20 to 60 micro meter, resulting in reducing the flow.

3.2. Verification of long-term clogging

Long-term clogging tests were conducted to verify the influence of inputting slurry over a long period of time, on the reduction of flow, and, the influence of back pressure on clogging. Long-term tests were conducted in case 1 and case 6, basically under the same condition with short-term clogging tests. The differences are the number of times of input (42 times per cycle for long-term clogging test), and the process of applying back pressure after each cycle. The objective of applying back pressure is to simulate the condition when the water level is drawing down rapidly in the upper reservoir, due to power generation.

Fig. 8 shows the test results of case 6 (long-term). Clogging was observed at all locations of slits, as the slurry have been inputted. In addition, flow decreased greatly accordingly. After third cycle, the flow have decreased by 99%. On the other hand, increase of flow was observed after applying back pressure. Approximately 60 to 70 % of the flow, compared to the previous flow cycle, was restored. However, though some of the fine particles deposited at the parallel plates were washed out, particles clogged inside the narrow slits were not washed out by back pressure, as shown in Fig. 9.

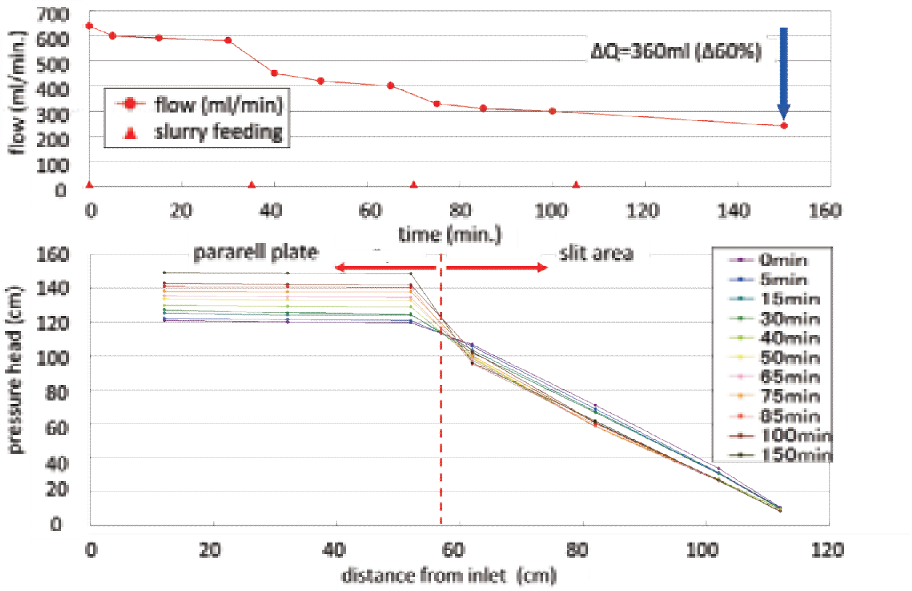


Figure 6. Flow and pressure head in case 1

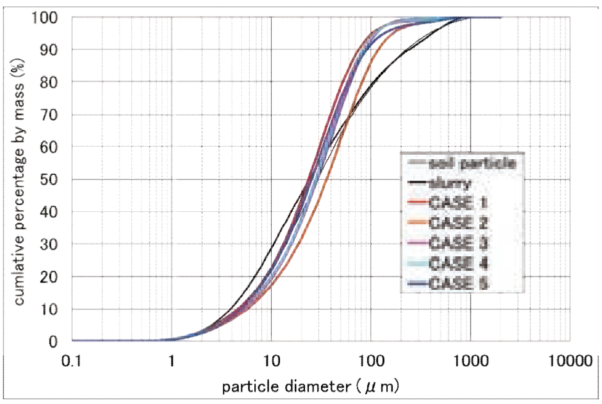


Figure 7. Particle size distribution after clogging tests (short term test)

Table 2. Results of clogging tests in each case

		The velocity ratio of each case against the velocity of the case 2					
		0.75		1		1.5	
		CASE 1		CASE 2		CASE 3	
area/slit	1mm² (1×1mm)	clogging ○	reduction rate of flow 54～63%	clogging ○	reduction rate of flow 52～53%	clogging ○	reduction rate of flow 44～46%
				CASE 4		CASE 5	
	2mm² (1×2mm)			clogging ○	reduction rate of flow 34～37%	clogging ○	reduction rate of flow 5～21%
						CASE 6	
	4mm² (2×2mm)					clogging ×	reduction rate of flow –

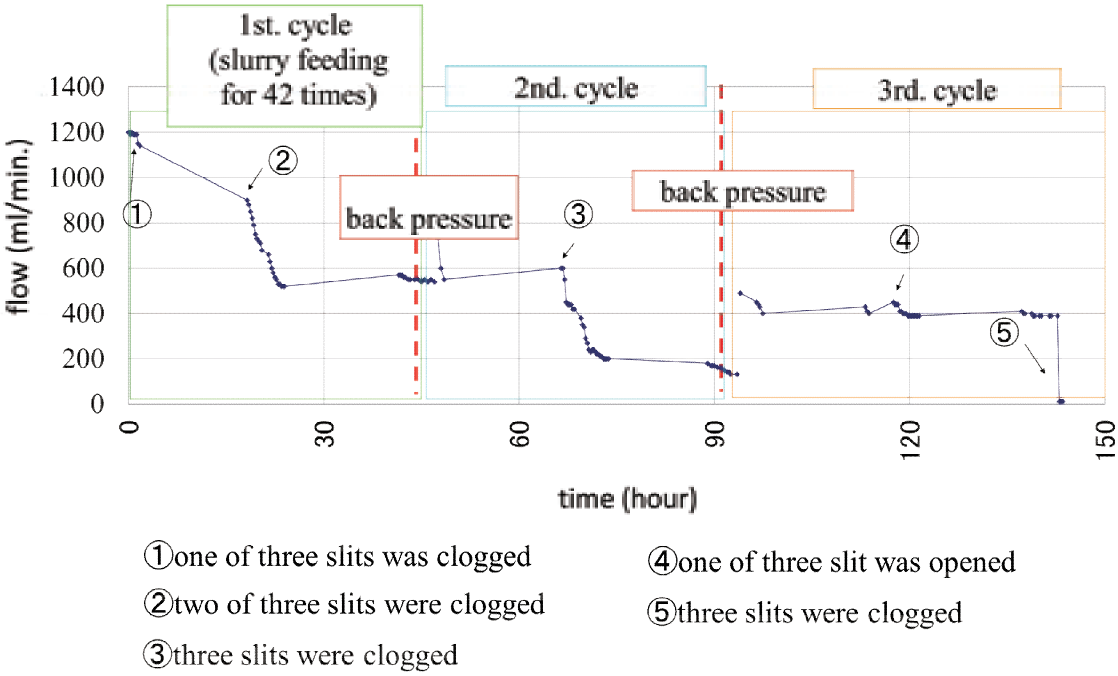


Figure 8. Result of clogging tests (Case 6)

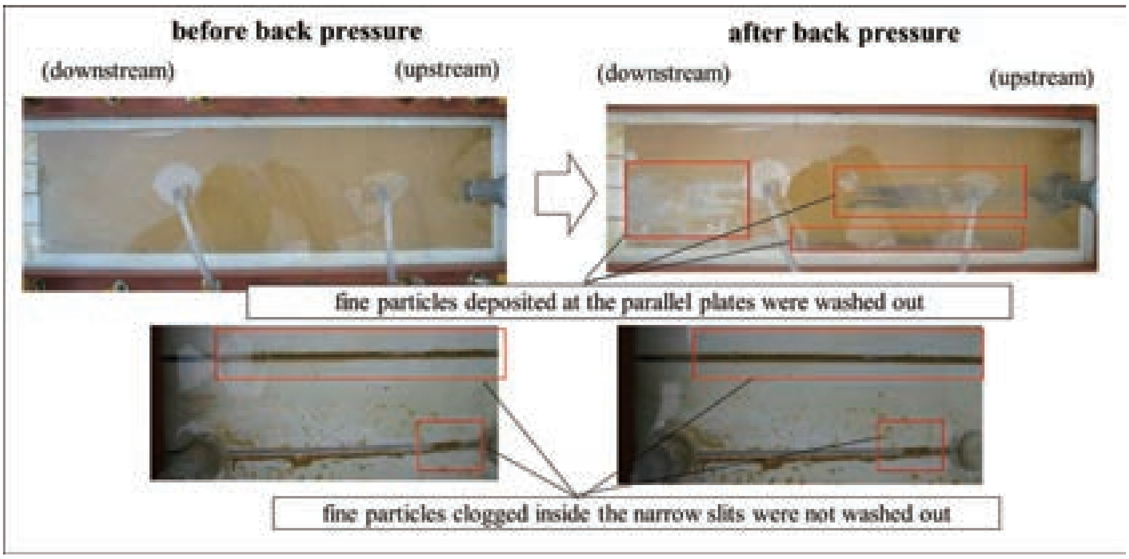


Figure 9. Situation after clogging tests (Case 6)

Fig. 10 shows the particle size distributions of the clogged soils. Compared to the short-term tests, particles that clogged in the long-term tests contained more fine particles, which indicates that fine particles will also be effective for clogging in long-term.
As a result, clogging promotion method was determined to be effective for reducing water leakage of the reservoir, since the soil particles will be clogged solidly in narrow spaces by inputting repeatedly, and would not be washed out by back pressure.

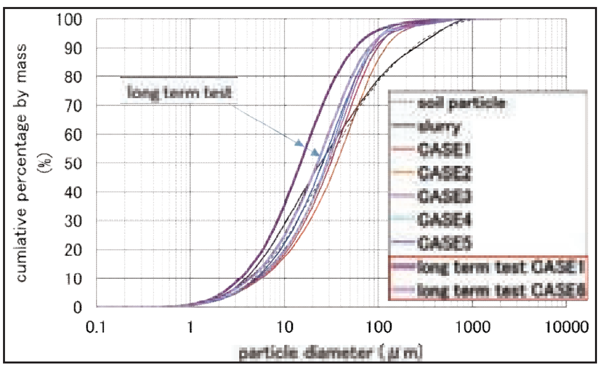


Figure 10. Particle size distribution after clogging tests (long term test)

4. EFFECTS OF THE METHOD IN FIELD TEST

In order to verify the effects of the clogging promotion method, field test was implemented at the south side of the reservoir, as shown in Fig. 11, where relatively numerous inlet holes were found in preliminary investigations of slopes by divers. The test site was encircled by a net to prevent soil particles from diffusing throughout the reservoir. In the field test , soil particles were input for four weeks. Input was repeated in the first two weeks at standard turbidities of 100, 50 and 30 ppm to grasp the tendency of turbidity reduction. In the second two weeks, relations between input, integrated turbidity and suction strength were identified. Particles were input at standard turbidities of 30 and 100 ppm in the third and fourth weeks, respectively. The total input of soil particles was 10.2 t and the integrated turbidity was 100 ppm-day.

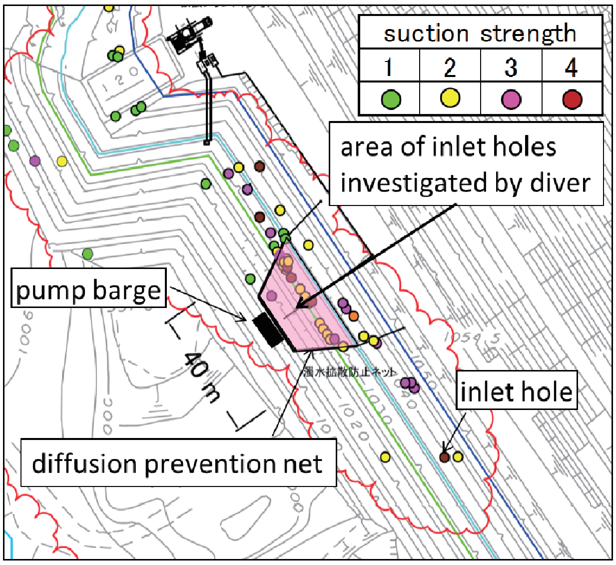
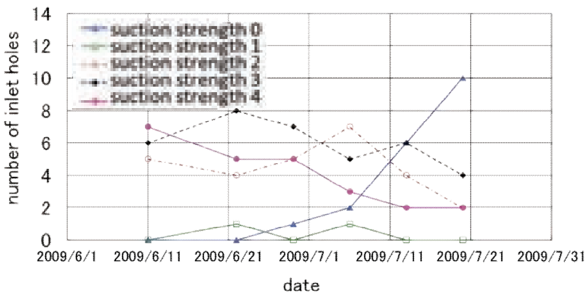


Figure 11. Area of inlet holes investigation

The effectiveness of the clogging promotion method was determined based on the increased or decreased number of inlet holes with different suction strength. Submersible investigations of inlet holes were made before field test, and, approximately once a week thereafter. Fig. 12 shows the results of submersible investigations. Inlet holes with a suction strength of 2 to 4, which were found in the preliminary investigation, was reduced. Inlet holes with a suction strength of 0 increased from none to 10, after the tests. The results therefore verified that the clogging promotion method was effective to some extent.



suction strength	flow velocity (cm/sec)
0	0.0
1	1.0
2	2.5
3	4.0
4	6.0

Figure 12. Result of inlet holes investigation

5. CONCLUSION

A study was made on the applicability of the clogging promotion method as an auxiliary method for grouting, which uses low-cost materials available in the vicinity of the reservoir site. Field and laboratory tests were conducted to decide slurry density for the clogging promotion method and to confirm the clogging effect. In addition, influence of back pressure were examined by laboratory tests. From the results we estimated that this method is applicable to the actual site. Therefore, the clogging promotion method was conducted in the actual leakage-prevention works as an auxiliary method for grouting, and proved to be effective to some extent. We are planning to make a report about further verification of the effect and durability of the clogging method in the near future.

ACKNOWLEDGEMENT
We would express our sincere thanks to Professor Emeritus Makoto Nishigaki, Okayama University, Tatsuo Ohmachi, Professor Emeritus, Tokyo Institute of Technology and Advisor to Japan Dam Engineering Center (JDEC), Dr. Norihisa Matsumoto, Advisor to JDEC, Mr. Joji Yanagawa, President, JDEC and Mr. Mitsuaki Mizuno, former director of Japan Water Agency for their kind guidance.

REFERENCES

Kawashima, F. and Tsukada, T. (2010): A Study for the behavior of groundwater flow along the open fissures with high dip angles, ICOLD symposium 2010, CD.